MTI

MTI Core Science Retrieval Algorithms

Christoph C. Borel, William B. Clodius, Anthony B. Davis, Barham W. Smith,
John J. Szymanski, James Theiler, Pierre V. Villeneuve and Paul G. Weber
Space and Remote Sensing Sciences Group
Mailstop C 323, Los Alamos National Laboratory
Los Alamos, NM 87545, USA
E-mail:cborel@lanl.gov WEB: http://nis-www.lanl.gov/~borel/
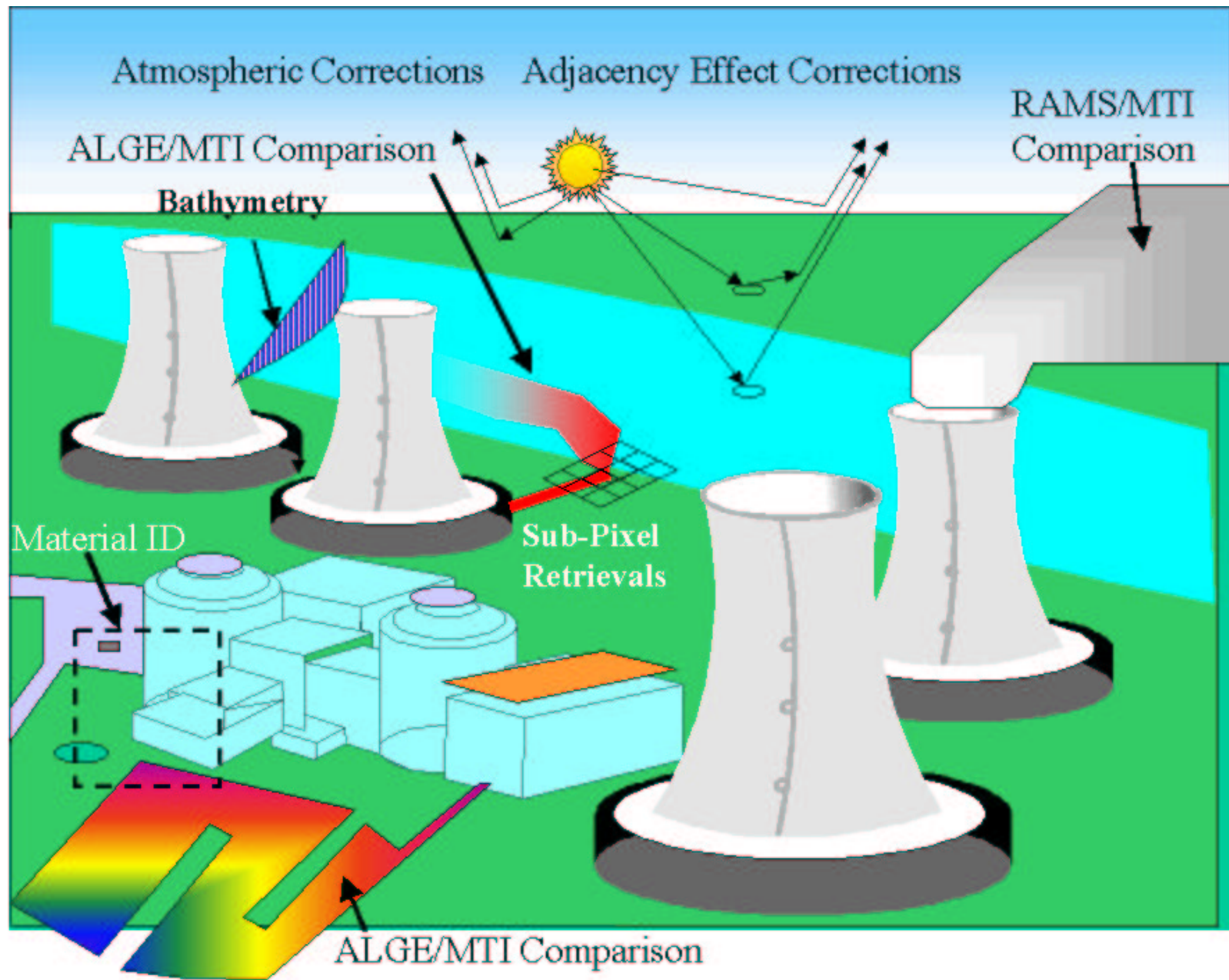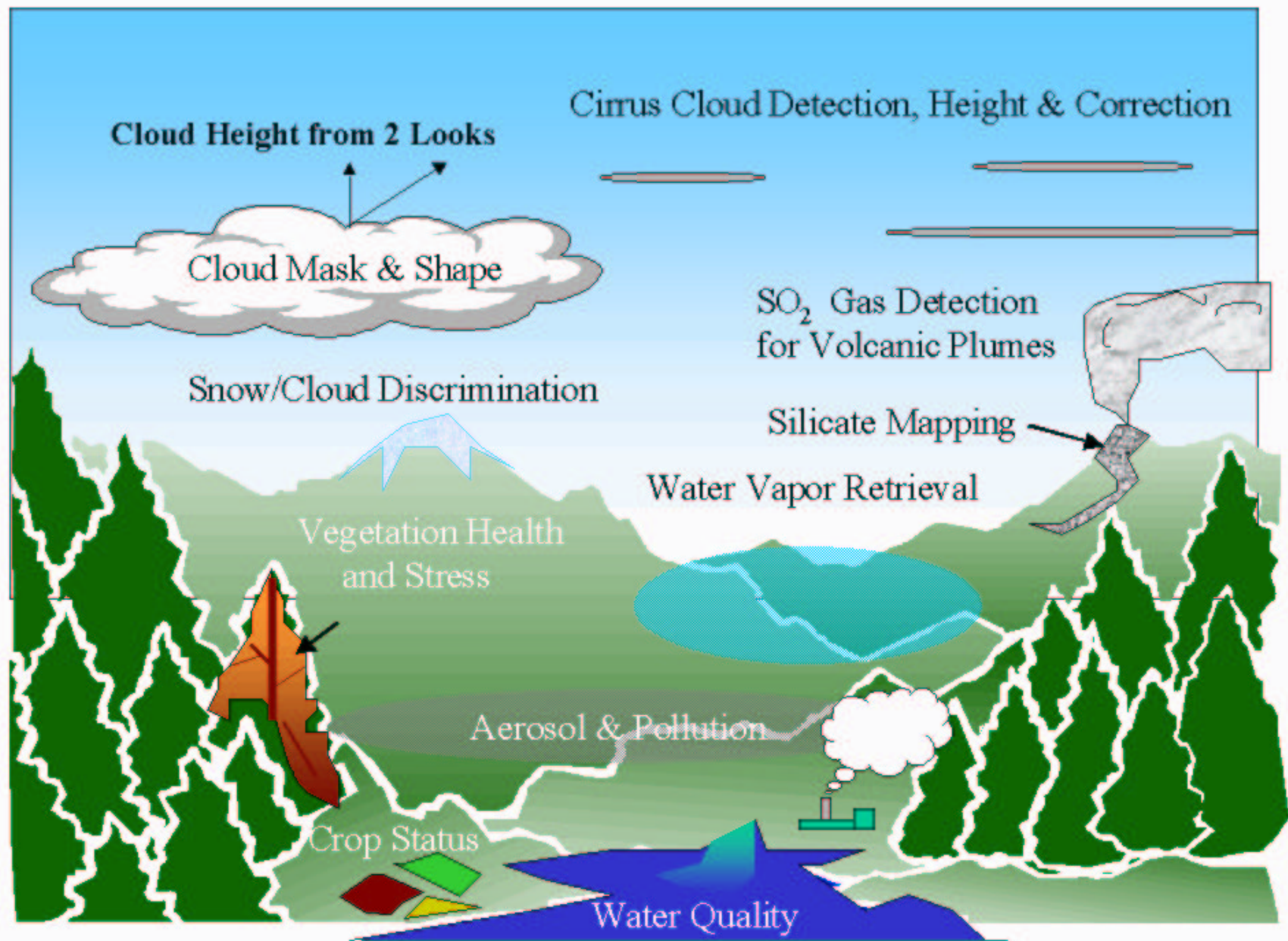(505)-667-8972 FAX (505)-667-3815

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    (b) Vegetation health status retrieval
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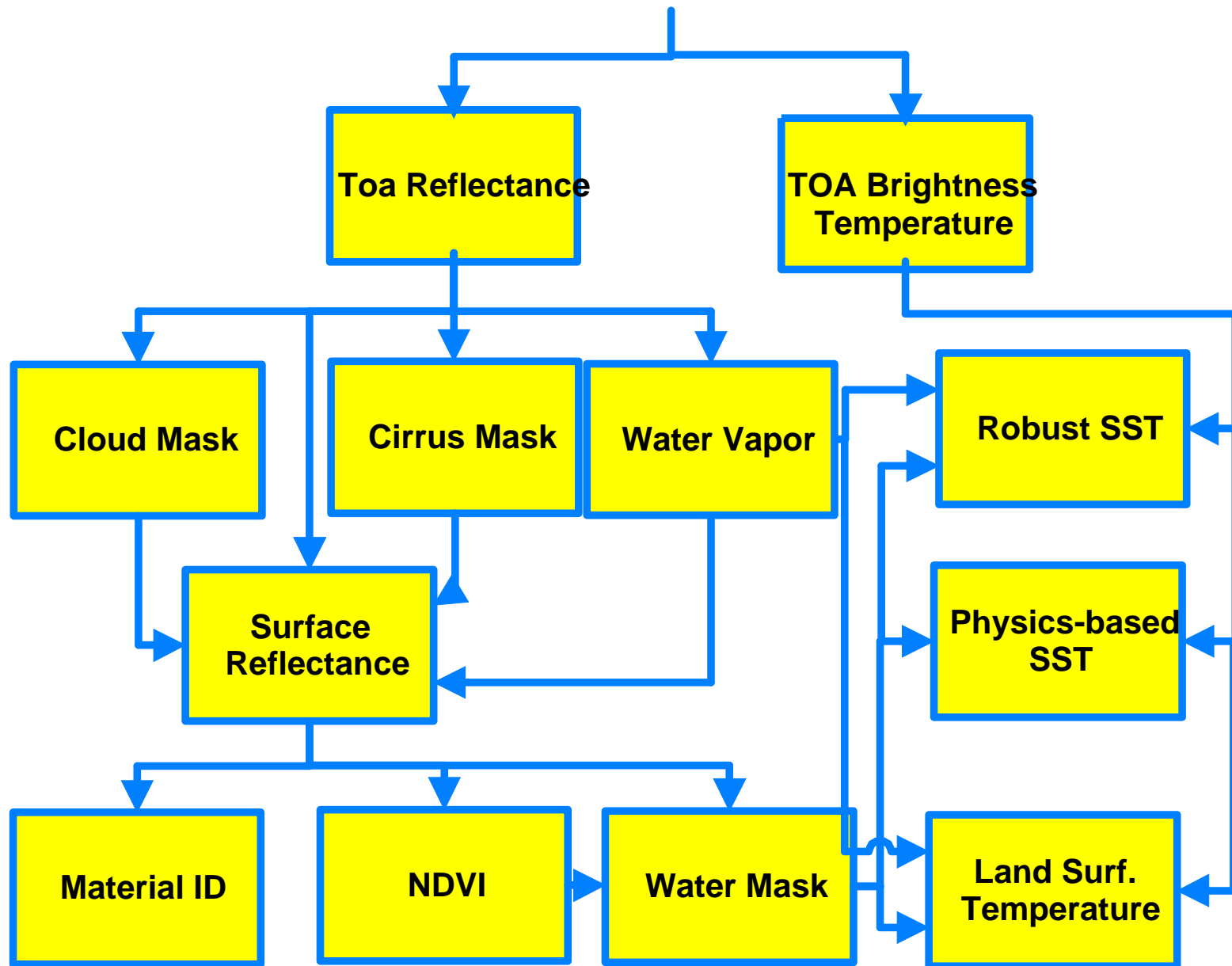5. Level-2 interactive analysis tool

6. Conclusions

MTI's Applications

Band Characteristics				Use in Science Analysis (D=Day, N=Night)						
Band	Wavelen. in μm	Color/ Region	Major Appl.	SST	Water Qual.	Water Vapor	Atm. Corr.	Veg. Str.	Cir. Det.	Class./ Mat.Id.
A	0.45-0.52	blue	Water		D		D			D
B	0.52-0.60	green	Soil/Veg.		D		D	D		D
C	0.62-0.68	red	Chloroph.		D		D	D		D
D	0.76-0.86	NIR	Veg.	(D)			D	D		D
E	0.86-0.90	NIR	H_2O Ref.	(D)		D	D			
F	0.91-0.97	NIR	H_2O Abs.	(D)		D	D			
G	0.99-1.04	SWIR	H_2O Ref.			D	D			D
H	1.36-1.39	SWIR	Cirrus				D		D	
I	1.55-1.75	SWIR	Veg.				D	D		D
O	2.08-2.35	SWIR	Geology				D	D		D
J	3.50-4.10	MWIR	Therm.	N						D+N
K	4.87-5.07	MWIR	Therm.	D+N				D		N
L	8.00-8.4	LWIR	Therm.	D+N				D		N
M	8.40-8.85	LWIR	Therm.	D+N				D		N
N	10.15-11.5	LWIR	Therm.	D+N				D		N

MTI's industrial facilities monitoring products.

Cloud Height from 2 Looks

Cirrus Cloud Detection, Height & Correction

Cloud Mask & Shape

SO_2 Gas Detection for Volcanic Plumes

Snow/Cloud Discrimination

Silicate Mapping

Water Vapor Retrieval

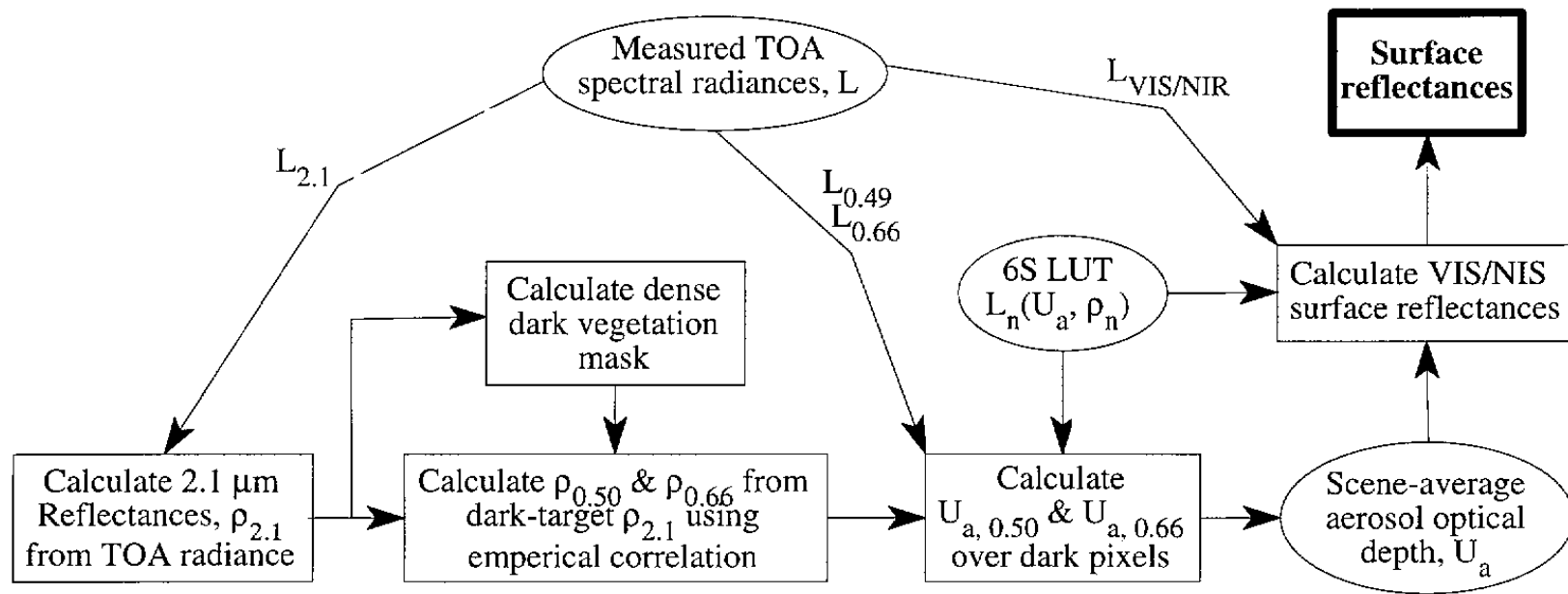Vegetation Health and Stress

Aerosol & Pollution

Crop Status

Water Quality

MTI's environmental science products.

MTI's industrial facilities monitoring and environmental Level-2 science product flow.

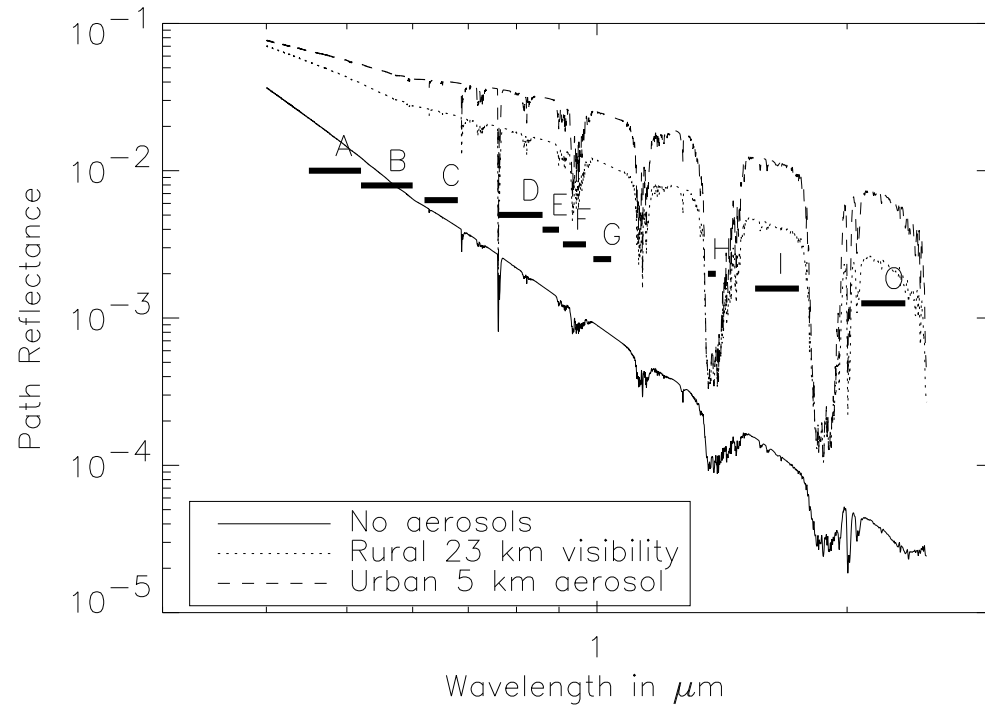# Land Products: Surface reflectance retrieval

1. Dense dark vegetation based atmospheric correction (AC)

Dense dark vegetation AC flow.

2. Water based atmospheric correction

MTI Band	Wavelength Range in μm	Landsat Band
A	0.45–0.52	1
B	0.52–0.60	2
C	0.62–0.68	3
D	0.76–0.86	4
E	0.86–0.90	
F	0.91–0.97	
G	0.99–1.04	
H	1.36–1.39	
I	1.55–1.75	5
O	2.08–2.35	7

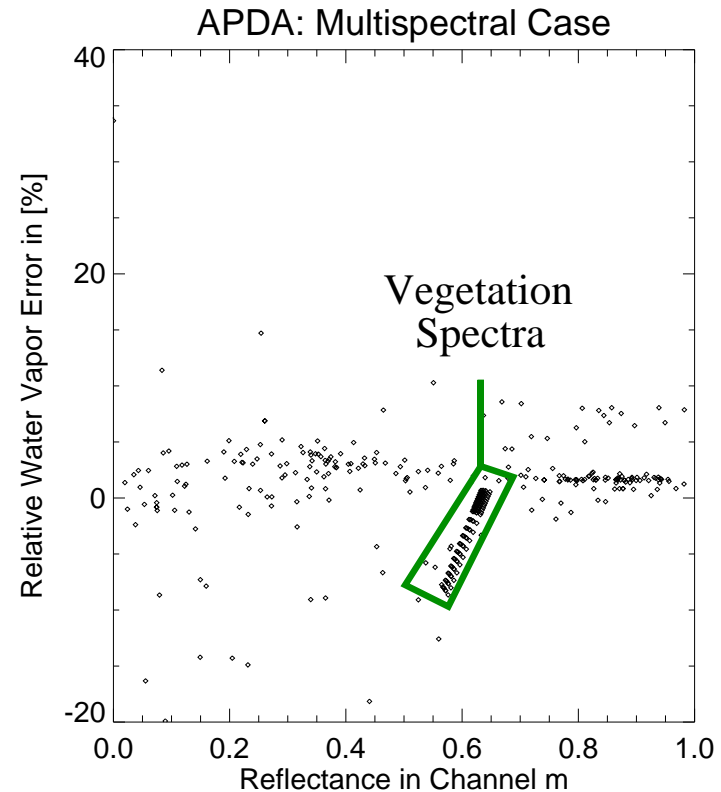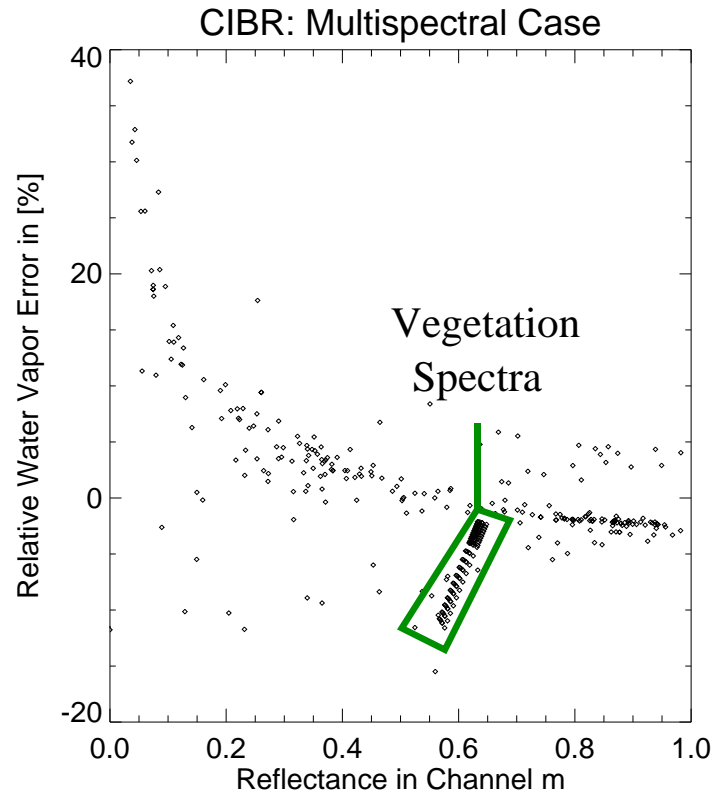Path reflectance correlated to wavelength in atmospheric windows

$$\rho^*_{i;corrected} = \rho^*_{i;TOA} - \rho_{i;path}, \quad \text{where} \rho_{i;path} = 10.^{a+b \ \log_{10}(\lambda_i)}. \tag{1}$$

Note: neglect the absorption through the atmosphere and local illumination geometry

Vegetation health status retrieval

1. Water Stress:

(a) Leaf water signature: 940 nm water absorption decreased

Relative water vapor error for CIBR and APDA ratios for many material including different vegetation canopies

(b) Temperature: Canopy temperature elevated during day
(c) Leaf drooping: Canopy angular reflectance lower

2. Nutrient stress:

(a) Leaf spectral signature: decreased chlorophyll → yellow leaves

(b) Canopy spectral signature: less dense canopies → decreased LAI
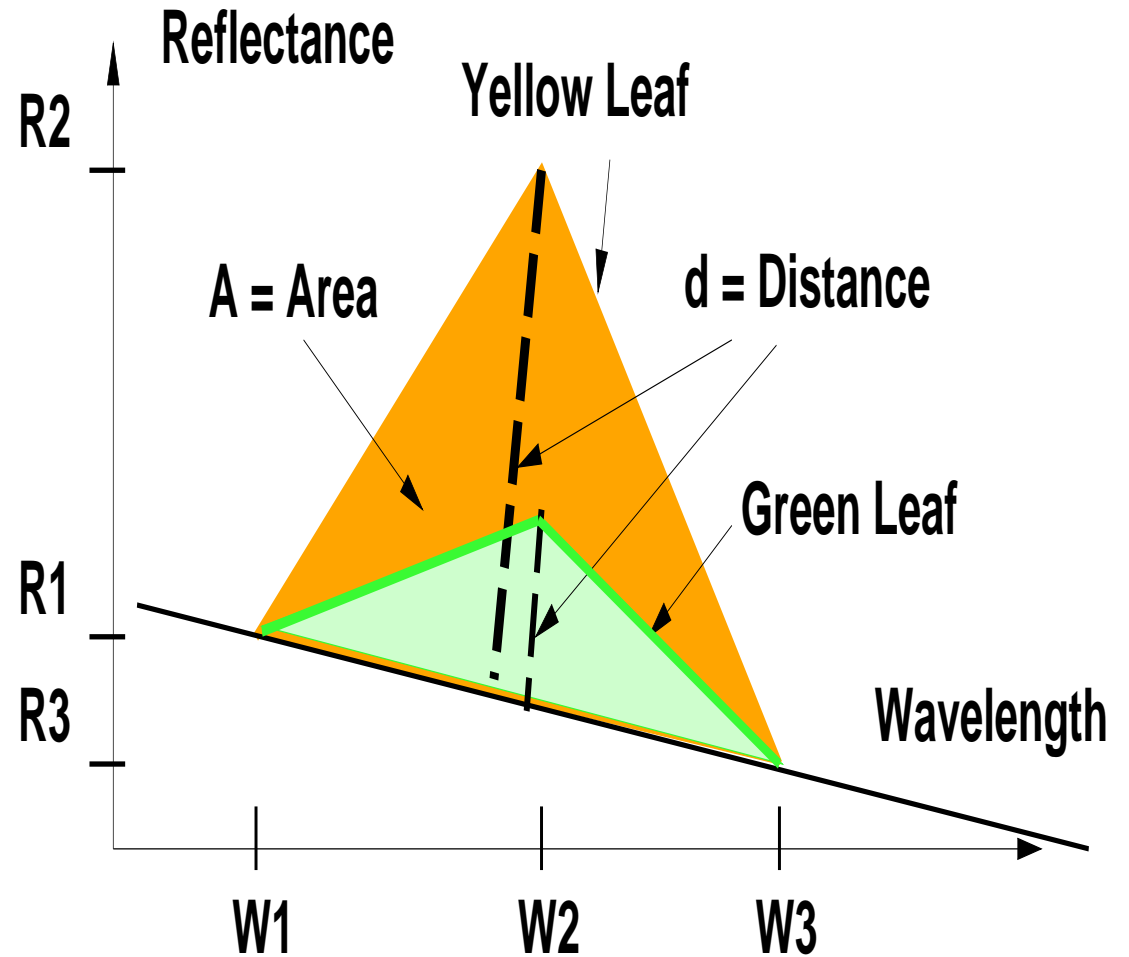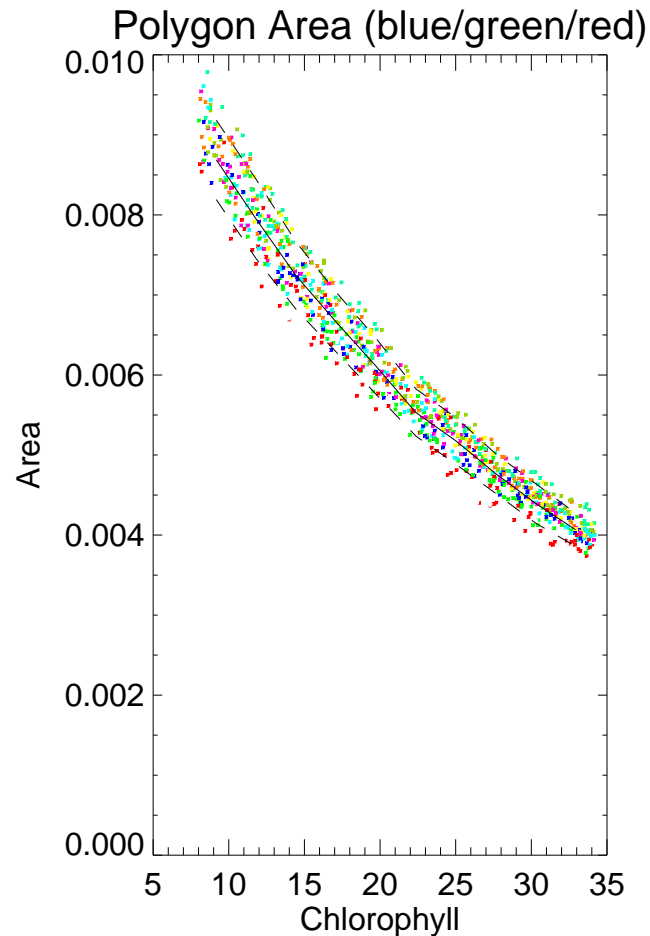
Three channel (A,B and C) measures of distance and area to quantify leaf yellowing
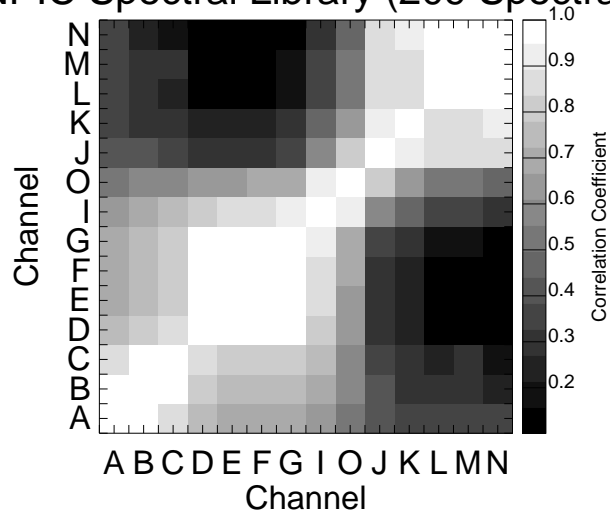
Material identification

Purposes:

- identify specific materials

- distinguish man-made objects from natural objects
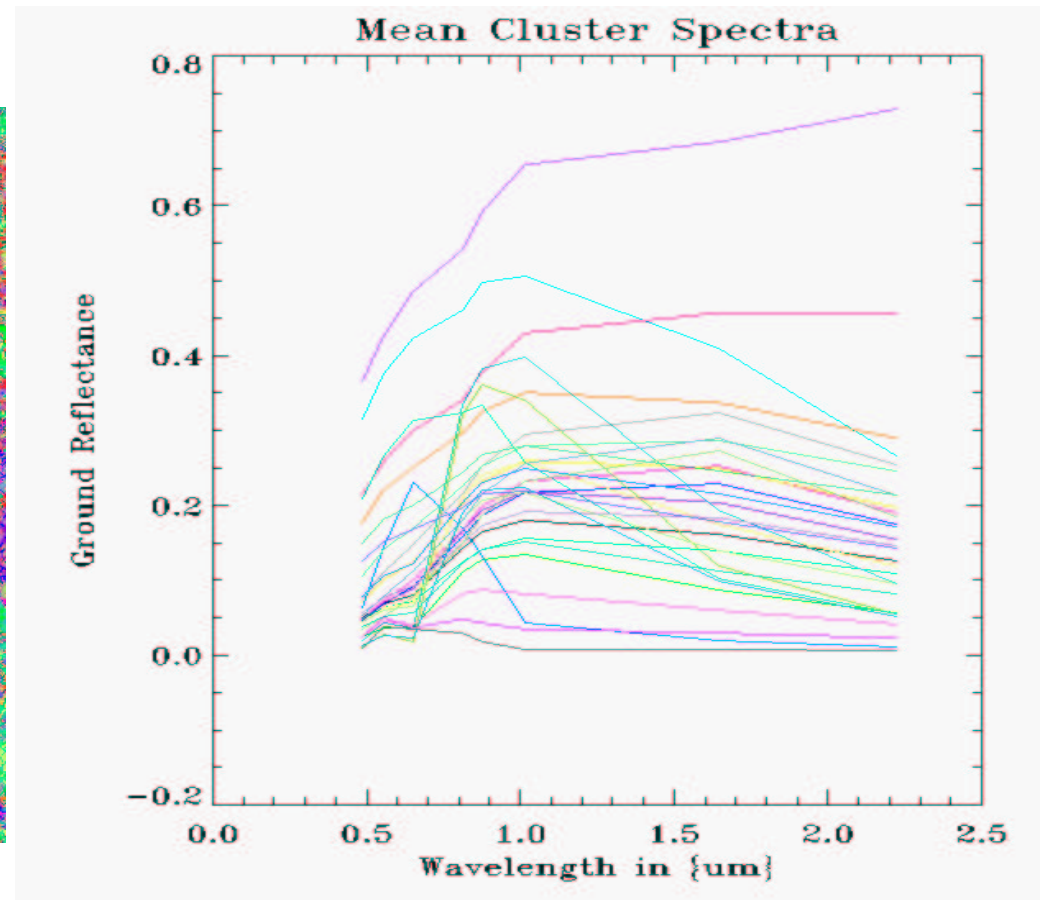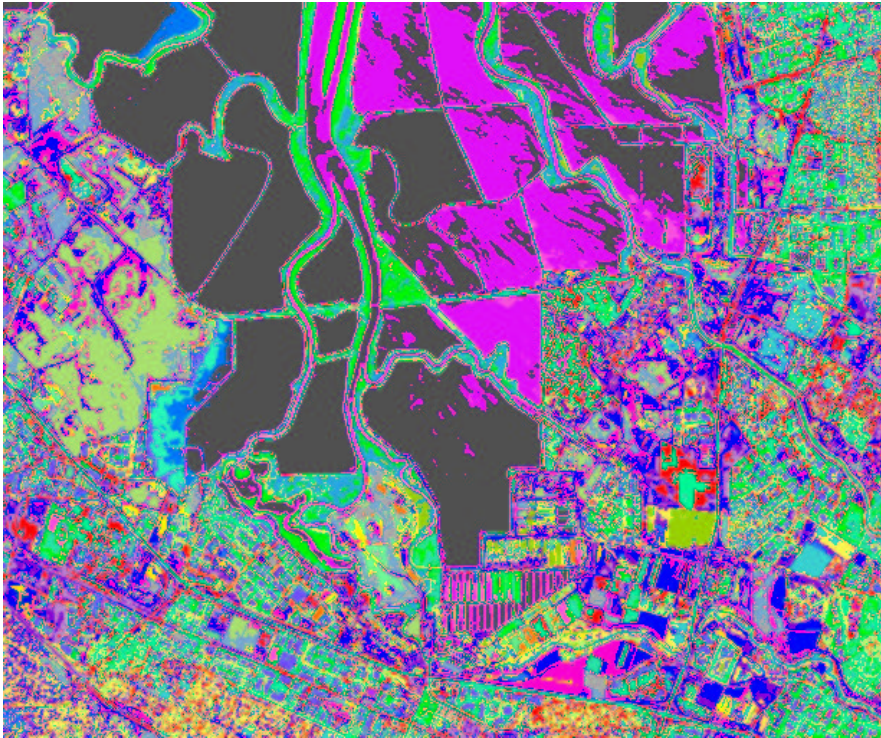
Implemented methods:

1. Un-supervised k-means clustering

2. Spectral angular mapper material identification

3. Spectral library based material identification

4. Supervised land cover classification

Correlation matrix of 209 materials for MTI channels

1. Un-supervised k-means clustering

Un-supervised clustering result of a scene over Moffet Field, CA.

2. Spectral angle mapper material identification (Boardman, 1993)

At pixel (i,j) SAM is given by:

$$\alpha_{i,j} = \cos^{-1}\left(\frac{\Sigma_{n=1}^{N} r_n t_{n;i,j}}{\sqrt{\Sigma_{n=1}^{N} r_n^2}\sqrt{\Sigma_{n=1}^{N} t_{n;i,j}^2}}\right) \tag{2}$$

where $\vec{r}$ is the reference spectrum and $\vec{t}_{i,j}$ is the measured spectral data cube.
Note: SAM insensitive to the illumination conditions!
Steps:

1. Select a reference spectrum vector in image

2. Normalize the spectral data cube

3. Perform SAM and display cumulative histogram of angle α.

4. Select a threshold on angle and display image $\alpha_{i,j} < \alpha_{thres}$

3. Spectral library based material identification

Steps

1. Select any pixel spectrum

2. Calculate the Mean Square Error (MSE) between measured reflectance $\vec{t}_{i,j}$ and k-th material spectrum $\vec{r}_k$.

3. Select then one of the close matches based on visual agreements and some additional knowledge about the scene.

4. Supervised land cover classification

Implemented: USGS land cover classification system ()=# of sub-classes

1. Urban or Built-up Land (7)

2. Agricultural Land (4)

3. Rangeland (3)

4. Forest Land (3)

5. Water (4)

6. Wetland (2)

7. Barren Land (7)

8. Tundra (5)

9. Perennial Snow or Ice (2)

10. Others (2)

Steps:

1. User selects a given sub-class

2. Marks a region using a polygon in the image

3. All spectra in the region are extracted

4. Compute mean and standard deviation

Water products: Water Masks, quality & SST

1. NDVI & Red - water mask:

$$WM_{simple} = (\rho_C < 0.3) \cap (NDVI < 0.041), \tag{3}$$

where $NDVI = (\rho_D - \rho_C)/(\rho_D + \rho_C)$.

2. Spectral water mask:

$$WM_{spectral} = (norm(\rho_D) \leq 0.25) \cap (NDVI \leq 0.) \cap (\rho_B/\rho_C > 1.), \tag{4}$$

where $norm(\rho_i)$ is computed by normalizing the channel i TOA reflectance between 0.0 and 1.0 so that 96% of the data lies in that interval.

3. Spatial water mask

$$WM_{spatial} = (WM_1 + WM_2 + WM_3) \geq 2, \tag{5}$$

$$\text{where} \quad WM_1 = (norm(\rho_D) \leq 0.25) \cap (NDVI \leq 0.), \tag{6}$$

$$WM_2 = (NDVI > 0.) \cap (norm(\sigma(\rho_D)) \leq 0.25), \text{ and}$$

$$WM_3 = (norm(\rho_D) \leq 0.25) \cap (HP(\rho_D) > 0.) \cap (norm(\sigma(\rho_D)) \geq 0.25).$$

Notation: $\sigma(\rho_i)$ is the standard dev. over 21x21 window and $HP(\rho_i)$ is the high-pass filtered image

Water quality retrieval

Purpose:

- Discharges delineate the thermal plume in the visible

- Absence of chlorophyll in water is an indicator of higher than 35 deg C water temperature

6S BRDF model for water:

- Specular reflection from water is modeled using Fresnel reflection.

- Surface slope distribution as a function of wind speed using the Cox-Munk model for solar glint.

- White-cap contributions for high wind velocities are included.

- Chlorophyll concentration effects on water color are modeled using Morel's (1988) model.

Steps:

1. Generate input file for 6S for given observation.

2. Run IDL wrapper program to generate top of the atmosphere radiances for channels A, B and C.

3. Run polynomial fitting program to fit the chlorophyll content as a function of channel radiance ratios A/B and B/C.
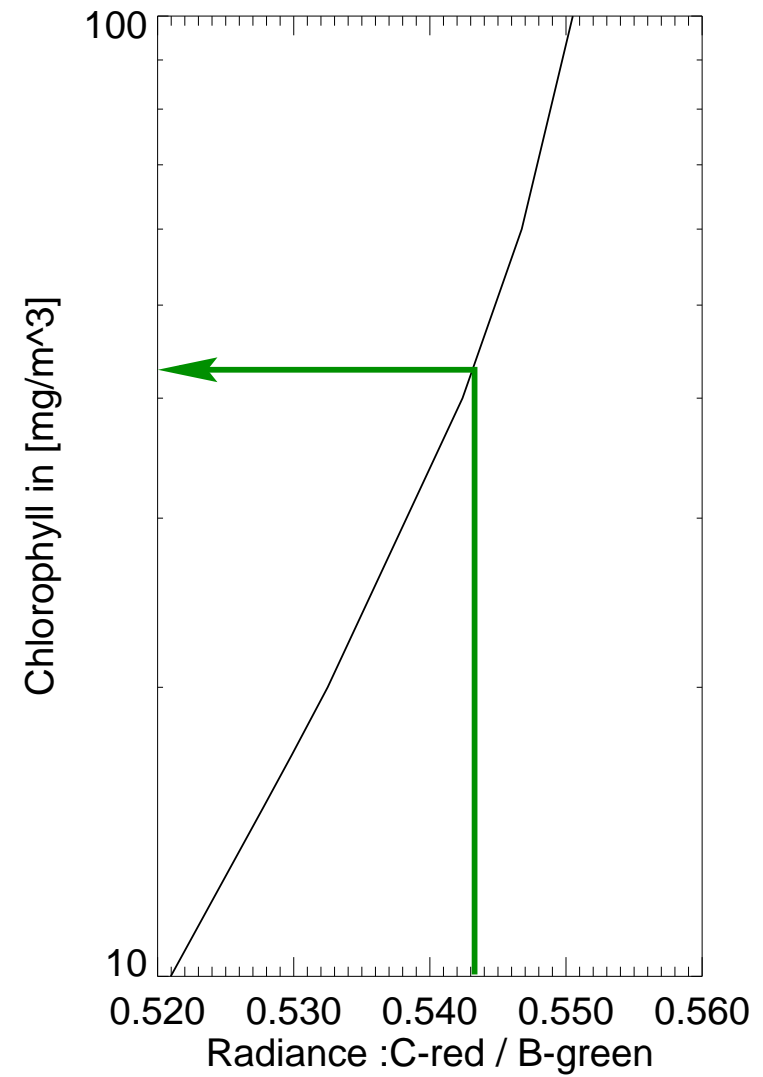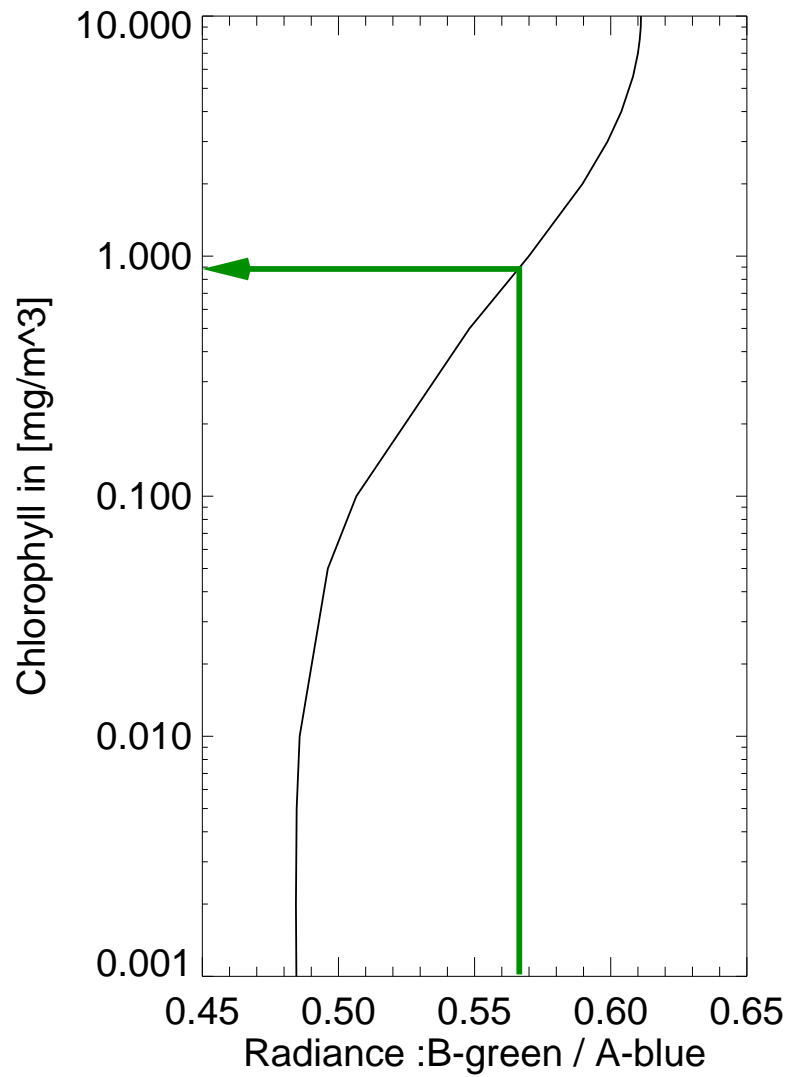
TOA Radiance ratios to retrieve chlorophyll content for ocean (left) and in-land waters (right).

Sea surface temperature retrieval

Two methods:

1. "robust" or statistical approach

2. "physics based" approach

1) Robust sea surface temperature retrieval:

- Requires no detailed knowledge of the atmosphere

- SST accuracy improved by assuming condition (dry, medium wet and wet)

- Two looks of water at nadir and 60° necessary

- Night mode: J , K , L , N and M (10 measurements)

- Day mode: K, L, M and N (8 measurements) + columnar water vapor

SST estimate $\hat{T}_w$:

$$\hat{T}_w = T_0 + \sum_{i=1\ or\ 2}^{5} a_i T_{w,i}(nadir) + b_i T_{w,i}(60deg),$$

where $T_{w,i}$ is the TOA brightness temperature in channel i.
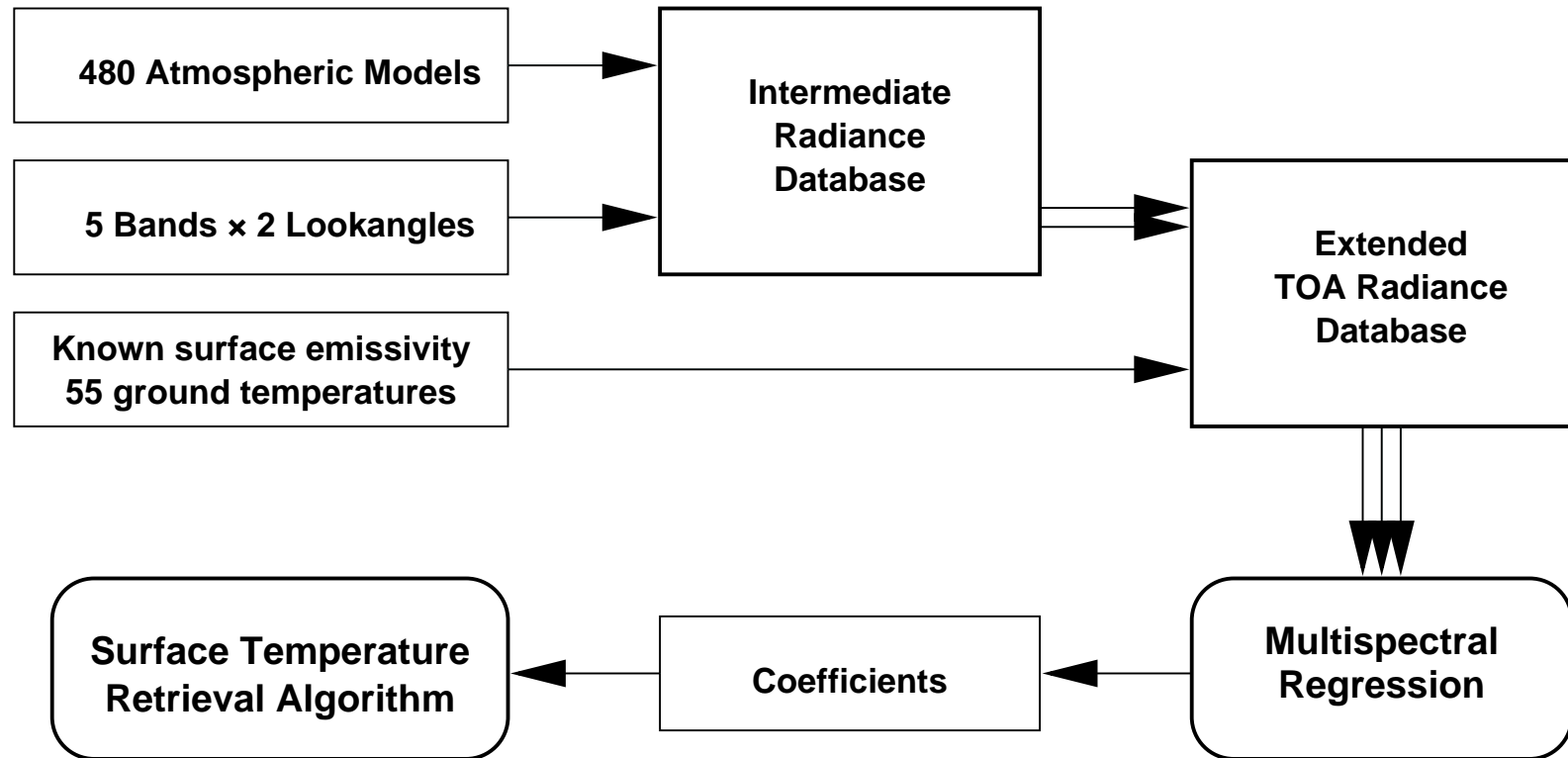
Flow diagram for the determination of the band coefficients for the robust SST retrieval.

2) Physics-based SST retrieval

Two versions:

- Single-pixel SST retrieval

- Multiple-pixel SST retrieval

Main idea: Atmospherically-corrected SST temperature should be the same in all thermal channels

Model for radiance $L_{m,i}$ for channel i at an observation angle of θ:

$$L_{m,i} = \varepsilon_{w,i} B_i(T_w) \tau_i(CW, \theta) + B_i(T_a)[1 - \tau_i(CW, \theta)] \tag{7}$$

where ε_w is the water emissivity, $B_i(T)$ is the band-averaged Planck function, subscripts w indicates water and a indicates the atmosphere.

Model for columnar water vapor dependent transmission:

$$\tau_i(CW, \theta) = \exp[-(\frac{A_i}{\cos\theta} + B_i(\frac{CW}{\cos\theta})^{C_i})] \tag{8}$$

where A_i, B_i and C_i are fitting parameters.

Single-pixel algorithm issues:

- Equations (7) and (8) form a nonlinear system of 5 (4 at night) equations with unknowns T_w, T_a and CW.

- Many solutions possible for T_a and CW minimizing standard deviation σ

- The error between retrieved water temperature $\hat{T}_w$ and actual water temperature is usually small.

Multi-pixel algorithm issues: Two different SST's in scene make T_a and CW solutions unique if atmosphere same over scene.
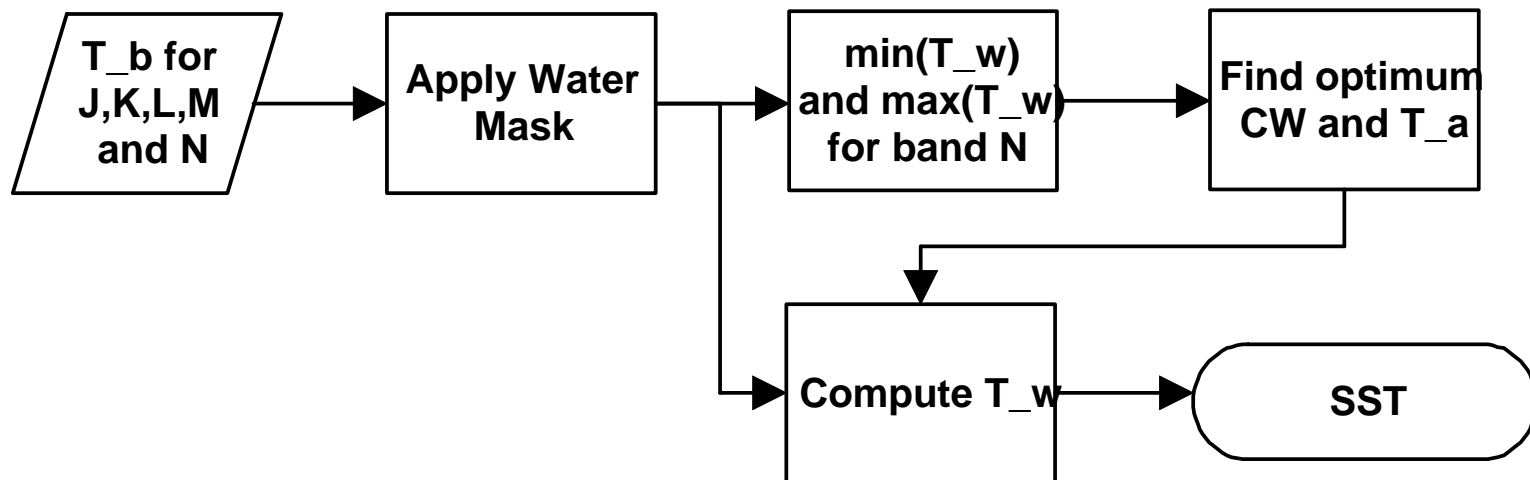
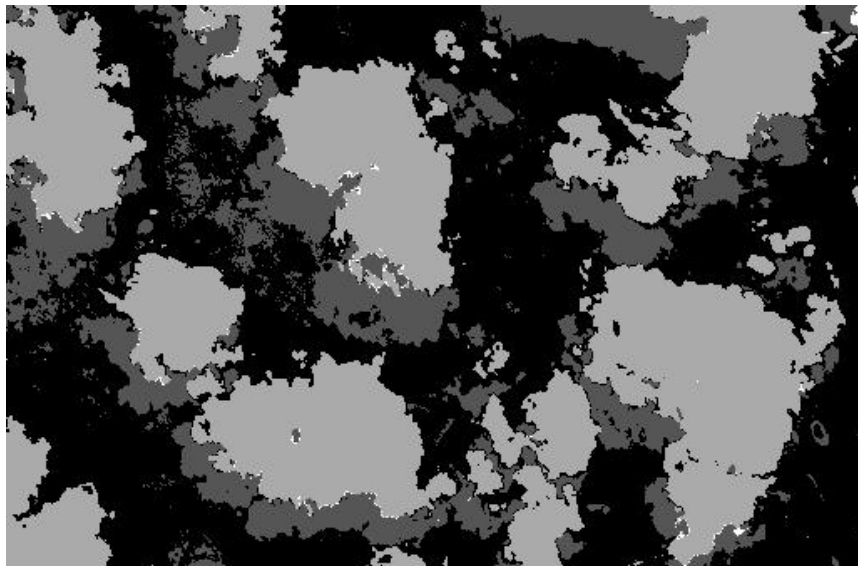Flow diagram for physics-based multi-pixel SST retrieval.

Atmospheric products: Clouds, cirrus and water vapor

Cloud and cloud shadow mask retrieval

Algorithm for generating a cloud mask CS:

$$CS = [R_9 < 1.82\ min(R_9)] \cap not(WM), \text{ where } R_9 = \frac{1}{9}\sqrt{\sum_{i=1}^{9} \rho_i^2}. \tag{9}$$

where 9 simulated MTI channels are used (all channels except H) and WM is a water mask.

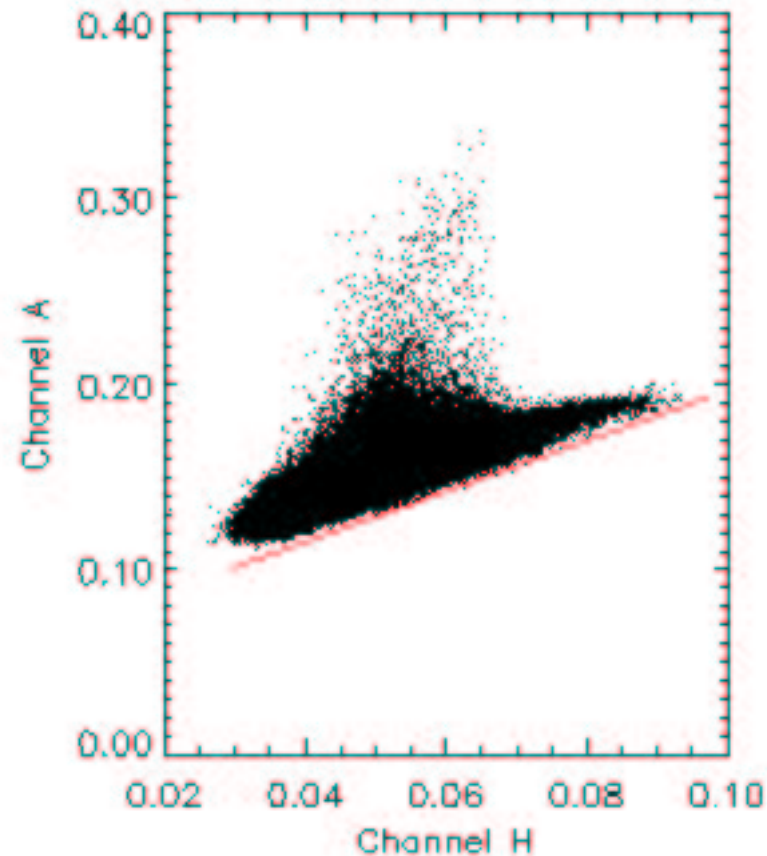Example of a cloud mask (light gray) and cloud shadow mask (dark gray)

Correcting for cirrus clouds

Data: AVIRIS over Coffeyville, Kansas on December 1, 1991

Steps:

1. Convert band averaged TOA reflectances

2. Manually chose regression coefficients a_i and b_i for axes: $x = \rho_H$ and $y = \rho_i$, where $i = A, B, C, D, E, F, G, I, O$:

Example of linear regression between channel A and H.

3. Correct reflectance in channel i:

$$\rho_i(cirrus\ corrected) = \rho_i - (a_i + b_i smooth(\rho_H, 21)) \qquad (10)$$
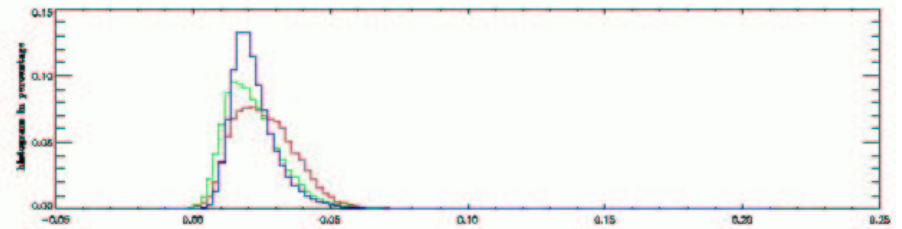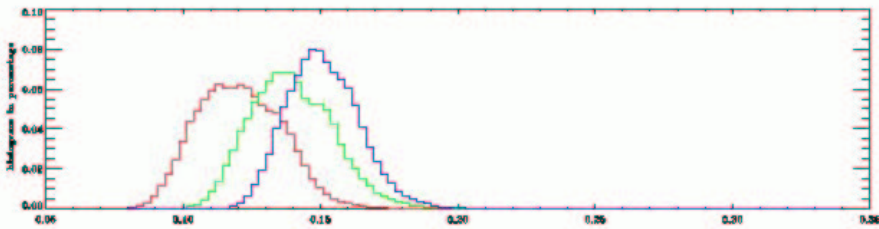
Example of true color cirrus scene ($R = \rho_C$, $G = \rho_B$ and $B = \rho_A$) on left and after cirrus correction on right with histograms below.

Water vapor retrieval: CIBR and APDA

1. Continuum Interpolated Band Ratio (CIBR):

$$CIBR = \frac{\omega_E L_E + \omega_G L_G}{L_f} \tag{11}$$

where L_E, L_F and L_G are TOA radiances, $\omega_E = .551$ and $\omega_G = .448$.
Comments:

- Works for bright surfaces $CIBR \approx \tau_{CW}$ for $\rho > 0.1$

- For dark surfaces $CIBR = f(L_{path}) \neq \tau_{CW}$ for $\rho < 0.1$

$\rightarrow$ need method to work over water for robust SST!

2. Atmospherically Pre-corrected Differential Absorption (APDA):

Observation: Scale lengths of atmospheric water vapor larger than ground features such as water
$\rightarrow$ water vapor continuous across a boundary of water to land
  APDA formulation using in-scene radiances:

$$APDA = \frac{\omega_E(L_E - fmin(L_E) + \omega_G L_G - fmin(L_G)}{L_f - fmin(L_F)} \tag{12}$$

where the terms $fmin(L_i)$ are an approximation of the path radiance with the factor f between
0.0 and < 1.0.

Steps for "dark/bright" APDA:

1. The water mask WM or alternatively a dark mask DM is computed using TOA reflectances in channels C and D.

2. "near water" or "near dark" target mask:

$$NMask = DILATE(DILATE(Mask, kernel), kernel) \cap DILATE(Mask, kernel),$$

where $Mask = \{WM,\ DM\}$.

3. The user specifies a factor f.

4. Plot and a point scatter plot of APDA ratio versus reflectance ρ_E.

5. Repeat steps 3&4 until the points of both classes line up horizontally.
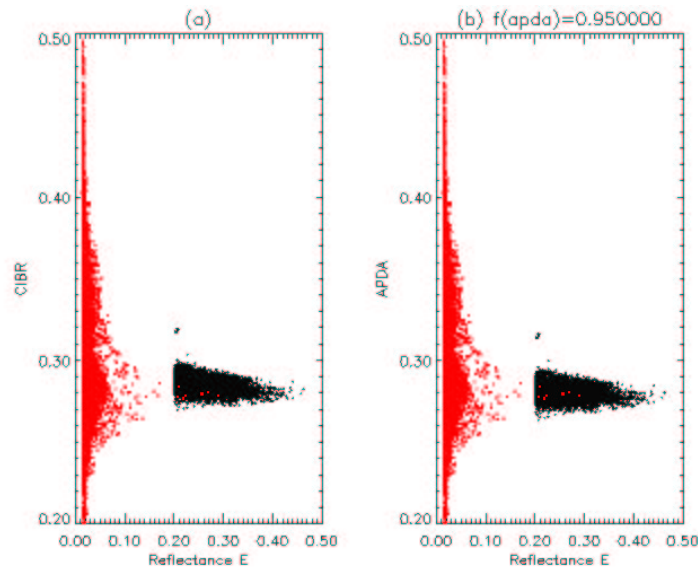
Scatterplot of (a) CIBR and (b) "dark/bright" APDA ratios as a function of ρ_E for dark (gray) and bright adjacent areas (black)
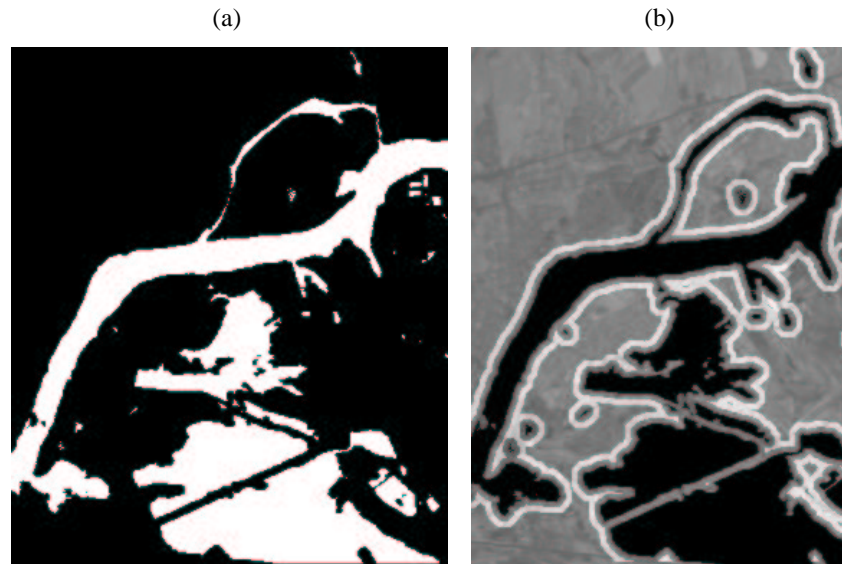
(a) NDVI&ρ_C based water mask and (b) "near dark" water pixels in white used for dark/bright based APDA


(a) CIBR and (b) dark/bright based APDA for a partial scene with a river

Level-2 Interactive Analysis Tool (IAT)

Salient features:

- The program is built of many individual algorithms (some Level-2 products have several choices) each with a set of inputs and outputs.

- While the program is run interactively results are displayed visually and the user can set thresholds etc.

- The user's actions are all stored in a journal file which can later be used to re-play the session or used to process other scenes or provide support in developing or de-bugging complex retrievals.

- The user can select to output images and scene specific settings to a hyper text mark-up language (HTML) file for documentation purposes with included references to GIF and JPEG format images for important results like images, spectra and scatter plots.

- MTI channel and geometry specific interfaces to applications like MODTRAN can aid in the analysis and atmospheric correction.

Program organization:
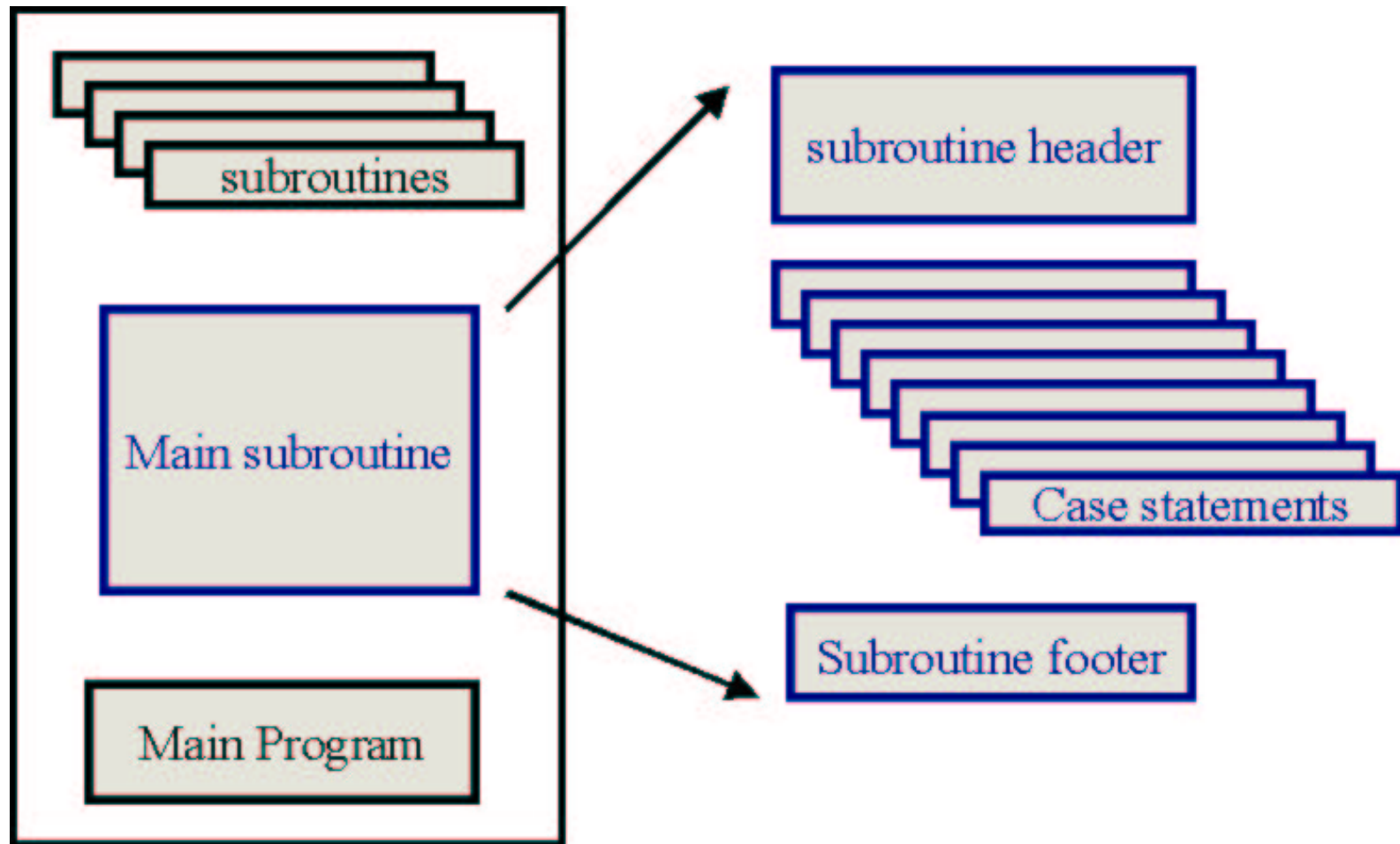
IAT consists of a large subroutine which is generated from individual code pieces

Menu Item	Sub Menu Item	IDL code
Input	Select another image	selectnew.pro
Journal	Play Journal	playjournal.pro
Journal	Record Journal	recjournal.pro
Journal	Stop Journal	stopjournal.pro
WEB	Output on	outputflagon.pro
WEB	Output off	outputflagoff.pro
WEB	Run Netscape	runnetscape.pro
Program	Edit IDL program	editpro.pro
Program	Make a PS table of Menu Structure	menutable.pro
Program	Make showmti and start over	mkmtiproc.pro
Display	Display channel	dispchan.pro
Display	Display PC	disppc.pro
Display	True Color Display	truecoldisp.pro
Display	ALL Color Display	allcoldisp.pro
Display	BW Display	bwimg.pro
Display	Histogram	plothist.pro
Display	Plot MTI Filter Functions	plotfilt.pro
Scatterplots	Scatterplot of 2 Variables	scatplot2.pro
Scatterplots	Scatterplot of 3 Variables	scatplot3.pro
Scatterplots	Histogram of 2 Variables	2dhist.pro
Scatterplots	2-D Histogram of all Channels	2dhistall.pro
Scatterplots	Dark Vegetation Scatter Plot	darkveg.pro
Reflectance	TOA Reflectance	toarefl.pro
Reflectance	Quick Ground Reflectance	qgndrefl.pro
Atmospheric correction	Automatic Atmospheric Correction	autoac.pro
Atmospheric correction	Estimate Path Radiance	estpath.pro
Atmospheric correction	Fix Cirrus Scattering	fixcirrus.pro
Water Mask	Water Mask	wmask.pro
Water Mask	Spectral Water Mask	wmspectral.pro
Water Mask	Spatial Water Mask	wmspatial.pro

Menu Item	Sub Menu Item	IDL code
Cloud Masks	Cloud Mask	cldmask.pro
Cloud Masks	Cloud+Shadow Mask	cldshdmask.pro
Cloud Masks	Cloud+Shadow-Water Mask	cldshdwatmask.pro
Water Vapor	CIBR	cibr.pro
Water Vapor	Direct APDA	apdadirect.pro
Water Vapor	Scatterplot APDA	apdascatter.pro
Material ID	NN clustering	nn.pro
Material ID	Least Square Fit to Library Spectra	lsqspec.pro
Material ID	Spectral Angular Mapper	sam.pro
Material ID	Supervised Clustering using two channels	svcluster.pro
MODTRAN	Run Modin37	runmodin37.pro
MODTRAN	Run Mod37	runmod37.pro
MODTRAN	Plot tape7	runplottape7.pro
Ratios	Ratio two channels	ratio.pro
Ratios	Ratio three channels	ratio3.pro
Ratios	NDVI	ndvi.pro
Ratios	General NDVI	gndvi.pro
Transforms	HSDC transform	hsdc.pro
Transforms	PC Analysis	pca.pro
Morphology	Clean Mask	cleanmask.pro
Control	Set Fraction for Quick scale	setqfrac.pro
Control	XloadCT24	xldct24.pro
IDL	Save Variables	savevar.pro
IDL	Restore Variables	restvar.pro
IDL	Call Insight	callinsight.pro
IDL	Stop - and Debug	stopanddebug.pro

Conclusions

MTI Level-2 science retrievals are:

- flexible to take scene-dependent paths can be taken through the processing chain
- flexible enough to allow quick changes and fixes if necessary
- complimentary existing general purpose software
- performing MTI specific tasks with:
  - a minimum of user interaction,
  - recording the user's action in a journal, and
  - creating automatic Web documentation of the process

Acknowledgements

- Department of Energy
- Steven Alferink, summer student, for spatial and spectral water masks
- Joseph Winkles, summer student, for prototype of browsing tool.